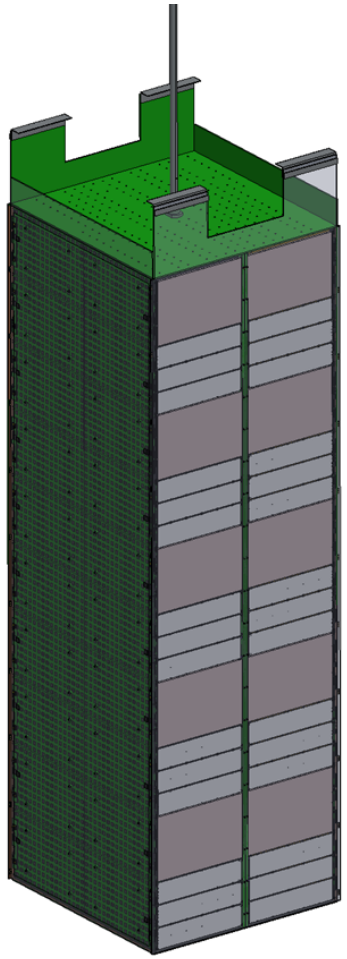
Module Assembly and Test Facility at FNAL

Content:

1. Mission need
2. Requirements
3. Scope, schedule, and cost
4. Resource gaps
5. Issues & risks

Module Assembly and Test Facility at FNAL



Mission - Testing of Near Detector TPC modules

Testing of 35(+5) production modules:

- Each completed module is warm and cold acceptance tested in dedicated single module cryostat at the Module Acceptance Test Facility (MATF) Functional and operational testing to verify performance of all subsystems
- After successful acceptance testing, modules are packaged and sent to the Near Site surface building for integration into module rows

Schedule (rough):

- Production Facility Design: Prelim – FY21 (extending to Dec 2021), Final – FY22
- Procurement and Production Facility Setup: FY23
- First Article TPC Module Assembly & Test: Late 2023
- Production of 40 ND LArTPC Modules: Early 2024 – Mid 2026
- Cryo testing routine:
  - dual cryostats for parallel testing one module in cryostat 1 while assembling and preparing the other module for cryostat 2
  - Allows transfer of LAr from one cryostat to the other with minimal losses

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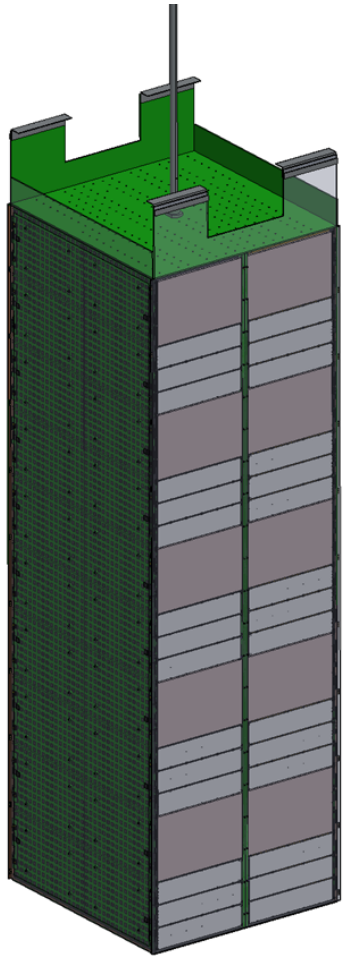

Requirements – facility and cryogenic system

- ❑ High-bay sufficient for cleanroom for ~4m-tall module assembly and storage for subsystem components
- ❑ Mezzanine structure for cryostat(s)
- ❑ Crane with ~4m clearance above cryostat for module installation/removal
- ❑ Cryostat(s) capable of hosting ~4m x 1m x 1m module. Two cryostats to parallelize assembly and testing
- ❑ External system for LN_2 and LAr storage & delivery of liquid and gaseous cryogens and venting of gaseous cryogens
- ❑ Proximity system for LAr purification, transfer and recirculation of LAr, cooling and warmup of 2 x 7000 L cryostats
- ❑ Process and safety PLC-based control systems
- ❑ ODH safety system

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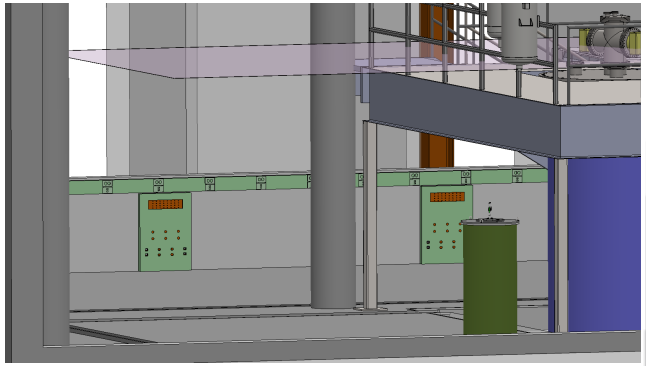
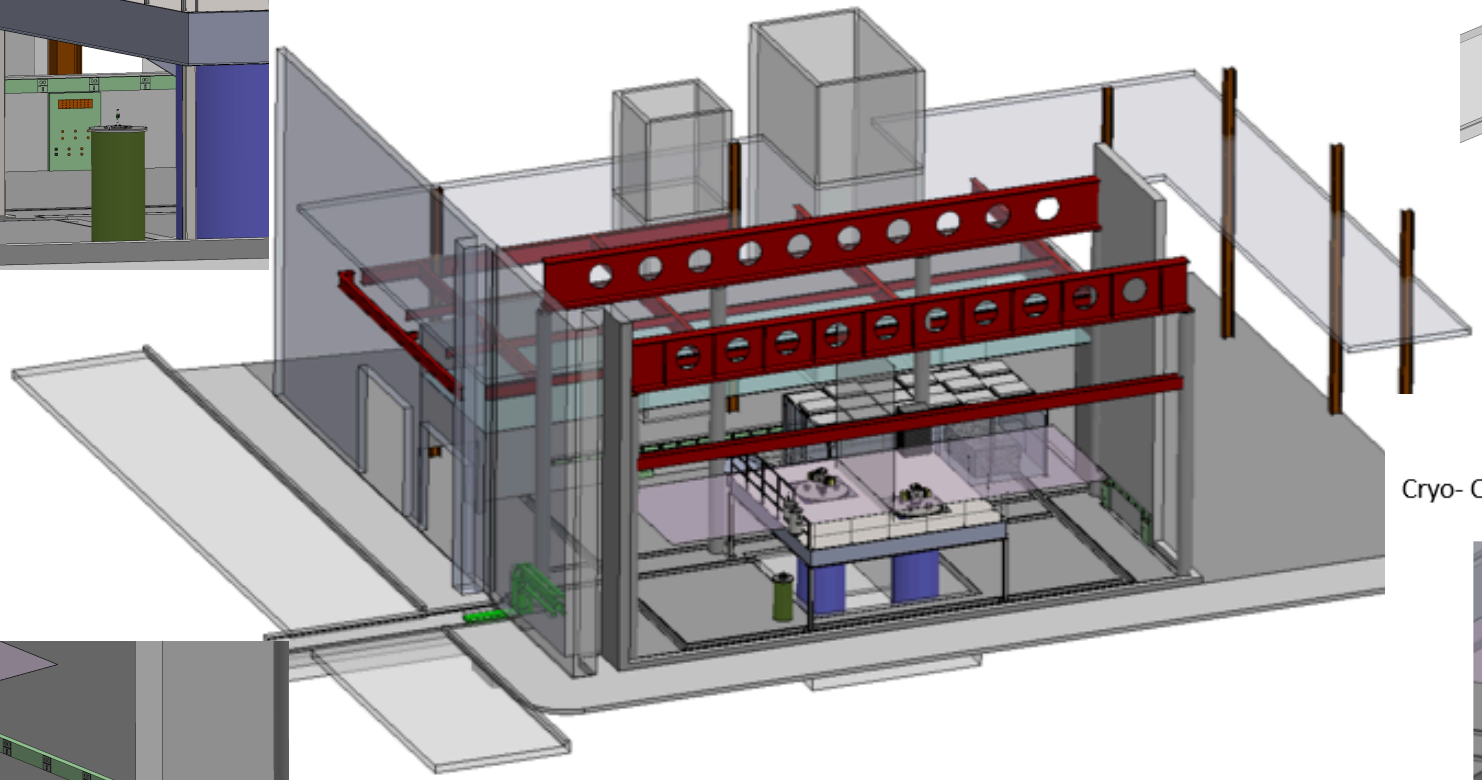
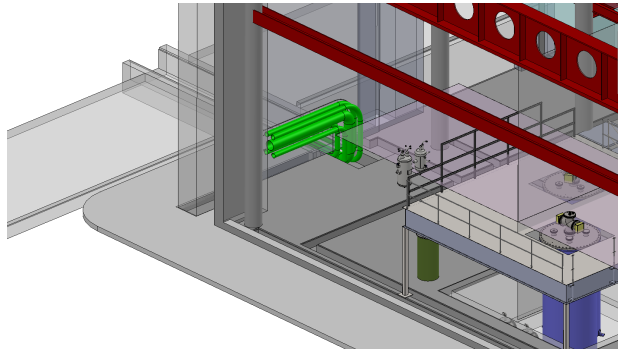


Channel Raceway
Provides Power & Data

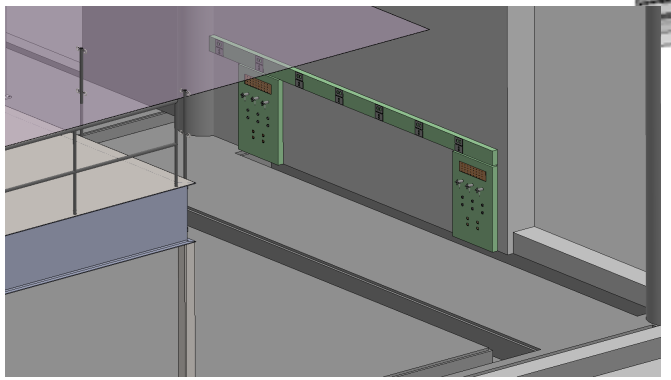


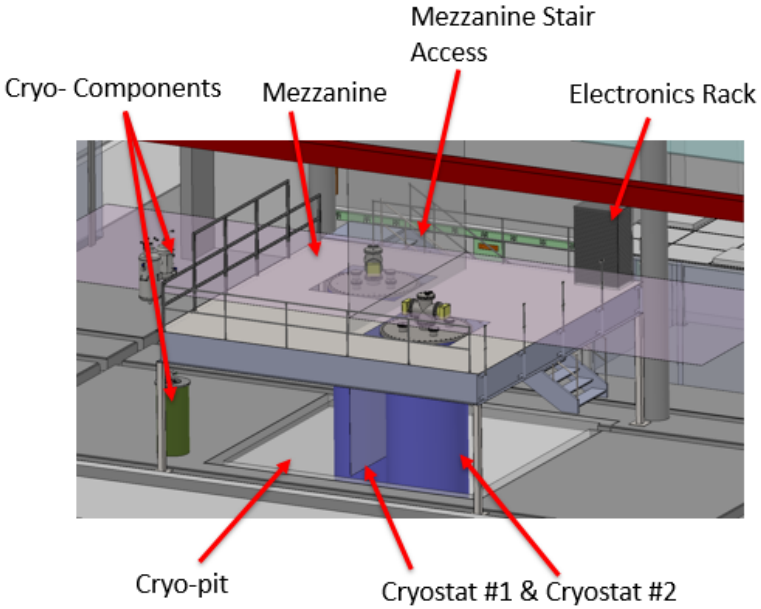


Incoming/Outgoing Cryogenics

Service Panels:

- Compressed Air
- Nitrogen
- Vacuum
- Water





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Scope of cryogenic system (1)

The MATF Cryogenic Plant is required to support operations of two cryostats operated in parallel. The cryostats are vessels serving the purpose of housing TPCs in the volume of purified argon. Neither the cryostats, not their top plates (removable and fixed) are included into the scope for this Cryogenic Plant. The Cryogenic Plant has three cryogenic systems: External, Proximity and Internal, where:

- The External system is responsible for storage and supply of cryogens, venting of gases, gas analysis, regeneration of filtration media, electrical power, and PLC-based safety system.
- The Proximity system is responsible for all transport and distribution of liquid argon and nitrogen, removal and measuring of impurities from argon, recirculation, and filtration of boil-off argon gas.
- The Internal system is responsible for interfacing internal volume of the cryostats with cryogenic plant, distribution piping inside the cryostats, measurement of argon purity, temperatures, and levels.

In addition, there is a common process control system required for providing I/O management through PLCs-based controls and computers-based HMI for all 4 sub-systems.

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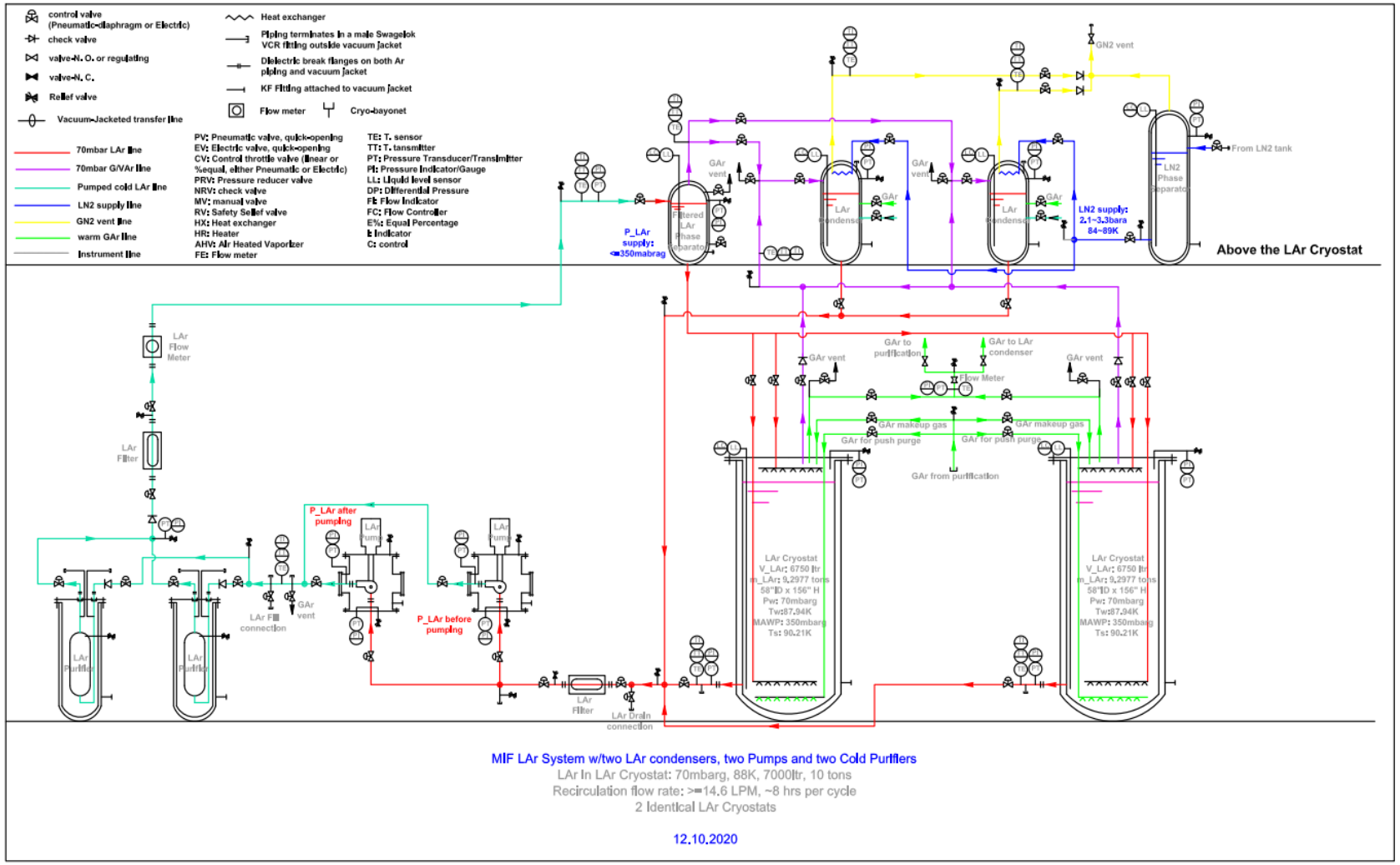
Scope of cryogenic system (2)



- This is a conceptual design
- Dual system will include 2 cryostats, two LAr pumps, 2 condensers and 2 LAr phase separators
- Dual design assures both, improved schedule and reliability in return at increased cost
- See supporting slides 1-4 for more technical details

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Cost and resources for cryogenic system (1)

- The delivery of the cryogenic plant will involve contributions for specific subsystems, both labor and M&S, from multiple organizations

- FNAL Neutrino Division will lead the cryogenic engineering in all phases of design, procurement, installation and commissioning for the MATF Cryogenic Plant

- It is agreed that the funding of labor of FNAL personnel and M&S for equipment is subsystem-specific:
  - External Cryogenics and MATF building safety, e.g. ODH, are funded by FNAL
  - Proximity and Internal systems are funded by the LBNF/DUNE Project
  - Cryostat and its safety are funded by the LBNF/DUNE Project

- Where a system, e.g. Process Controls, is common for all systems, the funding is proportionally divided between FNAL and LBNF/DUNE Project

- Additionally, the labor required to coordinate with the design of the cryostat and its top plate is funded by the LBNF/DUNE Project

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Cost and resources for cryogenic system (2)

Labor for Preliminary design CY2021:

Labor category	Total labor, FTE weeks	Total labor, % annual FTE	External, FTE weeks	Proximity, FTE weeks	Internal, FTE weeks	Cryostats, FTE weeks	Note
engineer	10.00	19.2%	2.60	4.90	1.50	1.00	
senior engineer	41.00	78.8%	14.00	20.10	5.20	1.70	effort for mech and electr/controls
principle engineer	18.00	34.6%	5.25	8.65	2.50	1.60	
designer	12.00	23.1%	3.20	5.90	2.10	0.80	
draftsman	10.00	19.2%	3.00	4.50	2.50	0.00	

Labor for Final design CY2022:

Labor category	Total labor, FTE weeks	Total labor, % annual FTE	External, FTE weeks	Proximity, FTE weeks	Internal, FTE weeks	Cryostats, FTE weeks	Note
engineer (all grades)	155.00	149.0%	41.55	74.70	15.50	23.25	
designer/draftsman	25.00	24.0%	6.73	12.02	2.50	3.75	

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Resource gaps

Beyond my pay grade

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Issues and Risks

- Technical:
  - Making safe and reliable flexible cryo connections to removable top lids
  - Making reliable removal of LAr and warmup to ambient for dual cryostat system
  - Placing multiple cryo valve boxes above cryostats' platform (support and clearance issues)

- Schedule
  - The schedule currently is resource driven

- Cost
  - Use of external subcontractors vs. Fermi internal personnel may present cost challenges

- Safety
  - Making the entire space ODH 0 to allow entry for non-qualified personnel

- Operational
  - Need to 24/7 support by cryo and technical personnel for 1.5 years of the testing campaign – resource issue

Module Assembly and Test Facility at FNAL – support slide 1

Table 1:

Cryostat Specifications

Item	Value	Notes
Number of Cryostats	2	
Cryostat Volume	~7000 L	Vacuum jacketed cylindrical vessel with 2-part top plate (fixed for cryo penetration and removable for TPC access)
Cryostat Height	~ 4.5 m	Reduce if possible
Operating Temperature	87 K - 300 K	
TPC clearance to avoid HV breakdown	?	HV cable is shielded
Operating Pressure	50-70 mbarg	
Maximum Allowable Working Pressure	350 mbarg	Cryogenic relief valve setting
Rated (Design) Pressure for cryostat	1 barg relative to atm	Consider 1034.21 mbarg (15 psig)
Rated (Design) pressure for top plate	1 barg relative to atm	Consider 1034.21 mbarg (15 psig)
Working Fluid	Liquid Argon	
Working Gas	Gaseous Argon	
Number of Purity Monitors	1	May not need?
LAr Purity as delivered (min)	TBD	Typical for FNAL contract (e.g. O2 < 1 ppm ; H2O < 1 ppm ; N2 < 2 ppm
LAr purity for operations (min)	500 µs	
TPC cooldown rate	< 40 K / hour < 10 K / m (vertically)	To ensure that temperature induced differential stresses do not exceed the yield stress of the detector components.
LAr recirculation rate	5-15 lpm	1 volume change per day (min)
LArTPC Min Thermal Load	88.3 W	DU-1002-3607
LArTPC Max Thermal Load	211.2 W	DU-1002-3607
Cabling and Electronics Thermal Load	?	?
Cryostat Evaporative Leak	26 L/day	Vendor estimate, 24" foam plug top
Ullage space	8%	Assumption
Annulus Insulation	Vacuum & MLI	Per vendor: CF Series, Cryofab
Lid Insulation	Vacuum & MLI	Could consider foam

Module Assembly and Test Facility at FNAL – support slide 2

Table 2:

External cryogenics specifications

Item	Value	Notes
Operating Temperature	87 K - 310 K	
Operating Pressure	50-70 mbarg	
Maximum Allowable Working Pressure	10 bara	Cryogenic relief valve setting
Rated Pressure	10 barg	
Working Fluid	Liquid Argon	
Working Gas	Gaseous Argon	
Working Fluid 2	Liquid Nitrogen	
Working Gas 2	Gaseous Nitrogen	
Liquid Argon Supply Nominal Flow Rate	~25 LPM	From dewar
Gaseous Argon Supply Nominal Flow Rate	40 lpm	TBD
Liquid Nitrogen Supply Nominal Flow Rate	5 lpm	TBD
Gaseous Nitrogen Supply Nominal Flow Rate	N/A	TBD
LAr Storage Tank Volume	> 7000 L	TBD
LAr Storage Tank Size	?	TBD
LN Storage Tank Volume	?	TBD
LN Storage Tank Size	?	TBD
High Pressure Vent: Argon	10 barg	verify
High Pressure Vent: Nitrogen	10 barg	verify
Low Pressure Vent: Nitrogen	1 barg	verify
Number of Purity Monitors	1	
Regeneration system	1	To regenerate external filters
Regeneration system heater	1	10 kW
Regeneration system HP Argon panel	1	
Regeneration system LP panel	1	
Analyzers	3	O2, N2, H2O

Module Assembly and Test Facility at FNAL – support slide 3

Table 3:

Internal Cryogenics Specifications

Item	Value	Notes
Operating Temperature	87 K - 310 K	
Operating Pressure	50-70 mbarg	
Maximum Allowable Working Pressure	350 mbarg	
Rated Pressure	1 barg relative to atm	
Working Fluid	Liquid Argon	
Working Gas	Gaseous Argon	
Liquid Argon Supply Nominal Flow Rate	5-15 LPM	1 volume change per day (min)
Gaseous Argon Nominal Flow Rate	up to 40 lpm	to ensure up to 1.5 m/hr piston purge

Module Assembly and Test Facility at FNAL – support slide 4

Table 4:

Proximity cryogenics specifications

Item	Value	Notes
Operating Temperature	87 K - 310 K	
Operating Pressure	50-70 mbarg	
Maximum Allowable Working Pressure	350 mbarg	Cryogenic relief valve setting
Rated Pressure	10 barg to atm	11 bar differential to vacuum
Working Fluid 1	Liquid Argon	
Working Gas 1	Gaseous Argon	
Working Fluid 2	Liquid Nitrogen	
Working Gas 2	Gaseous Nitrogen	
Liquid Argon Supply Nominal Flow Rate	5-25 LPM	Up to 25 lpm from the dewar. up to 15 lpm from the pump
Gaseous Argon Nominal Flow Rate	up to 40 lpm	TBD later based on overall requirements
Liquid Nitrogen Supply Nominal Flow Rate	up to 5 lpm	TBD later based on condensing needs (2x2.5 kW)
Gaseous Nitrogen Supply Nominal Flow Rate	0	not required for cryostats, but may be needed for EIRC
Number of Condensers	1 (+1)	Probably 2
Number of LAr Phase Separators	1 (+1)	Probably 2
Number of LAr Pumps	1 (+1)	Probably 2
Number of LAr Cold Purification Stands	1 (+1)	Min of 1
Number of LAr in-line Filters	1 (+1)	What's this?
Number of inline GAr heaters	1	To provide warm gas to cryostats
Number of LN Phase Separators	1	may not need if separation is done in condensers
Number of GAr Vaporizers	1	
Number of GN2 Vaporizers	1	
Number of Warm Filters	0/1	what's this?
Number of Flow Meters	2	For each pump
Number of Purity Monitors	1	
High Pressure Vent: Argon	10 barg	
High Pressure Vent: Nitrogen	10 barg	
Low Pressure Vent: Nitrogen	1 barg	